

**APPLICATION FOR UNITED STATES PATENT**

**FOR**

**METHOD AND APPARATUS TO MATCH OUTPUT IMPEDANCE OF  
COMBINED OUTPHASING POWER AMPLIFIERS**

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## **METHOD AND APPARATUS TO MATCH OUTPUT IMPEDANCE OF COMBINED OUTPHASING POWER AMPLIFIERS**

### **BACKGROUND OF THE INVENTION**

[0001] Outphasing transmitters may be used in stations of wireless communication systems such as, for example, base stations, mobile stations of cellular communication system and/or mobile unit and access point of wireless local area network (WLAN) and/or other types of wireless communication systems, if desired.

[0002] Outphasing techniques may combine two nonlinear radio frequency (RF) power amplifiers (PA's) into a linear power amplifier system. The two PA's may be driven with signals of different phases, and the phases may be controlled to provide an output signal with the desired amplitude.

[0003] The linear power amplifier system may include a combiner to combine the signal provided by the two nonlinear PA's. The combiner may include two transmission line couplers with shunt reactance. The power and efficiency of the outphasing transmitter may depend on the characteristics of the components and the architecture of the two transmission line couplers with shunt reactance.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0004] The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanied drawings in which:

[0005] FIG. 1 is a schematic illustration of a wireless communication system according to an exemplary embodiment of the present invention;

[0006] FIG. 2 is a block diagram of an outphasing amplifier according to an exemplary embodiment of the present invention; and

[0007] FIG. 3 is a schematic illustration of graphs helpful in demonstrating the efficiency of an outphasing amplifier according to an exemplary embodiment of the present invention.

[0008] It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

## **DETAILED DESCRIPTION OF THE INVENTION**

[0009] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention.

[0010] Some portions of the detailed description, which follow, are presented in terms of algorithms and symbolic representations of operations on data bits or binary digital signals within a computer memory. These algorithmic descriptions and representations may be the techniques used by those skilled in the data processing arts to convey the substance of their work to others skilled in the art.

[0011] It should be understood that the present invention may be used in a variety of applications. Although the present invention is not limited in this respect, the circuits and techniques disclosed herein may be used in many apparatuses such as transmitters of a radio system. Transmitters intended to be included within the scope of the present invention include, by a way of example only, cellular radiotelephone transmitters, two-way radio transmitters, digital system transmitters, wireless local area network transmitters, wideband transmitters, ultra wideband transmitters, and the like.

[0012] Type of cellular radiotelephone transmitters intended to be within the scope of the present invention include, although not limited to, Code Division Multiple Access (CDMA), CDMA-2000 and wide band CDMA (WCDMA) cellular radiotelephone transmitters for receiving spread spectrum signals, transmitters for global system for mobile communication (GSM), transmitters for third generation cellular systems (3G), orthogonal frequency division multiplexing (OFDM) transmitters and the like.

[0013] Turning first to FIG. 1, a schematic illustration of a wireless communication system 100 according to an exemplary embodiment of the present invention is shown. Although the scope of the present invention is not limited to this example, wireless communication system 100 may include at least one base station 110 and at least one mobile station 140. In some embodiments of the invention base station

110 may include a transmitter 120 and mobile station 140 may include a transmitter 150. At least one of transmitters 120 and 150 may be an outphasing transmitter with reactive termination. Reactive termination may be implemented, for example, in the form of a line coupler with shunt resistance, although the scope of the present invention is in no way limited to this respect.

[0014] Although the scope of the present invention is not limited in this respect, in some embodiments of the present invention, wireless communication system 100 may be a cellular communication system. Thus, base station 110 and mobile station 140 may be a base station and a mobile station of a cellular communication system.

In other embodiments of the present invention, wireless communication system 100 may be a WLAN communication system. Thus, base station 110 may be an access point (AP) and mobile station 140 may be a mobile unit such as, for example, a laptop computer, a tablet computer, a handheld device and the like.

[0015] Turning to FIG. 2, a block diagram of an outphasing transmitter 200 according to an exemplary embodiment of the present invention is shown.

Although the scope of the present invention is not limited in this respect, outphasing transmitter 200 may include nonlinear PA's 210, 220, a combiner 230, impedance transformer 280, a battery 285, and an antenna 290. In some embodiments of the invention, combiner 230 may include active devices, for example transistors (Q) 240, 245 and passive devices, for example, capacitors (C) 250, 255, inductors (L) 260, 265, and capacitor (C) 270.

[0016] Although the scope of the present invention is not limited in this respect, types of antennas that may be used for antenna 290 may include an internal antenna, a dipole antenna, an omni-directional antenna, a monopole antenna, an end fed antenna, a circularly polarized antenna, a micro-strip antenna, a diversity antenna and the like.

[0017] Although the scope of the present invention is not limited in this respect, impedance transformation 280 may transform, for example, the antenna impedance and/or load impedance ( $Z_{load}$ ), for example,  $Z_{load} = 50 \text{ Ohm}$  to intermediate impedance ( $Z_{intermediate}$ ) for example,  $Z_{intermediate} = 20 \text{ Ohm}$ . In this exemplary embodiment, battery 285 may provide direct current (DC) feed to active devices 240, 245 through the impedance transformer 280.

[0018] Although the scope of the present invention is not limited in this respect, combiner 230 may include two C-L-C PI ( $\pi$ ) converters. The first  $\pi$  converter may include C 250 (C\_A), L 260 (L\_PI) and a portion of C 270 (C\_PI). The second  $\pi$  converter may include C 255 (C\_B), L 265 (L\_PI) and a portion of C 270 (C\_PI). The first and the second  $\pi$  converters may convert the impedance of Zintermediate to the transistors 240, 245 impedance ( $Z_{PA}$ ). In some embodiments of the invention C 270 may be expressed as  $C_{PI} = 2 \cdot C_{\pi}$ . The capacitance of  $C_{\pi}$  and the inductance of inductor 260 or inductor 265 ( $L_{\pi}$ ) may be expressed calculated using the following equations:

$$(1) \quad C_{\pi} = \frac{1}{\omega_{CENTER} \cdot \sqrt{2 \cdot Z_{INTER} \cdot Z_{PA}}} \quad - \pi \text{-section capacitor;}$$

$$(2) \quad L_{\pi} = \frac{\sqrt{2 \cdot Z_{INTER} \cdot Z_{PA}}}{\omega_{CENTER}} \quad - \pi \text{-section inductor;}$$

wherein  $\omega_{CENTER}$  may be the center frequency of the signal that received from PA's 210 and 220.

[0019] Although the scope of the present invention is not limited in this respect, in some alternate embodiments of the present invention, the first and the second  $\pi$  converters may include second harmonic traps (not shown), which may be used to remove the second harmonic of transistors 240, 245, thus reducing the voltage peaking at the transistors. Although the scope of the present invention is not limited in this respect, other harmonic components may be filtered by  $\pi$ -section capacitor C\_A (referenced 250) and/or capacitor C\_B (referenced 255).

[0020] Although the scope of the present invention is not limited in this respect, shunt reactance may cause admittance shifts ( $\pm j \cdot BS$ ) wherein, BS is an amount of reactive admittance shift measured in mhos (e.g.  $1/\Omega$ ). For example, positive admittance shift  $+j \cdot BS$  may be accomplished by providing a shunt capacitor with the capacitance equal to  $BS/\omega_{CENTER}$  Farads. In the same fashion, negative admittance shift,  $-j \cdot BS$ , may be accomplished by providing a shunt inductor with an inductance equal to  $1/(BS \cdot \omega_{CENTER})$  Henry. In embodiments of the present invention, the admittance shifts may be added to capacitors C\_A and C\_B. These shifts may be defined in terms of  $K_{BS}$  which is the ratio of shift impedance to maximum power PA load impedance  $Z_{PA}$ .  $K_{BS}$  may be expressed as follows:

$$(3) \quad K_{BS} = \frac{1/BS}{Z_{PA}}$$

wherein  $K_{BS}$  represents BS in terms of  $Z_{PA}$ . For example,  $K_{BS}$  may be about 4 and  $Z_{PA}$  may be related to the optimum PA load at maximum output power.

[0021] Although the scope of the present invention is not limited in this respect, capacitor  $C_A$  may be calculated according to the following equation:

$$(4) \quad C_A = C_\pi - \frac{1}{3\omega_1^2 \cdot L_{RES}} - \frac{Z_{PA1} \cdot K_{BS}}{\omega_1}$$

wherein  $\omega_1$  is the fundamental harmonic of the input signal,  $L_{RES}$  may be the resonance of the second harmonic trap, and  $Z_{PA1}$  may be the output impedance of transistor 240. In embodiments of the invention, capacitor  $C_A$  may be designed to have a positive value.

[0022] Although the scope of the present invention is not limited in this respect, capacitor  $C_B$  may be calculated according to the following equation:

$$(5) \quad C_B = C_\pi - \frac{1}{3\omega_1^2 \cdot L_{RES}} + \frac{Z_{PA2} \cdot K_{BS}}{\omega_1}$$

wherein  $Z_{PA2}$  is the output impedance of transistor 245. In some embodiments of the

invention, the term  $\frac{1}{3\omega_1^2 \cdot L_{RES}}$  in Equations (4) and (5) may represent compensation for the admittance shift of the second harmonic resonator, although the scope of the present invention is not limited in this respect. In some other embodiments of the present invention, the second harmonic may not be used. For those embodiments, the

term  $\frac{1}{3\omega_1^2 \cdot L_{RES}}$  in Equations (4) and (5) may be omitted.

[0023] Although the scope of the present invention is not limited in this respect, transistors 240 and 245 may include bipolar transistors, field effect transmitters (FET), metal oxide substrate field effect transistors (MOSFET), Heterojunction Bipolar Transistors (HBT), Complementary Metal Oxide Semiconductors (CMOS), High Electron Mobility Transistors (HEMT), Laterally Diffused Metal Oxide Semiconductors (LDMOS), tubes, or the like. In some embodiments of the invention, transistors 240 and 245 may be bipolar transistors and equivalent to a

collector-emitter capacitance  $C_{CE}$ , which may be expressed as  $C_{CE} = \frac{Z_{PA} \cdot K_{BS}}{\omega_1}$  and may be absorbed in capacitor  $C_B$ . An equivalent to a collector-emitter inductance  $L_{CE}$  may be expressed as  $L_{CE} = \frac{\omega_1}{Z_{PA} \cdot K_{BS}}$  and may be absorbed in capacitor  $C_A$  in the form of equivalent negative capacitance  $-C_{CE} = -\frac{Z_{PA} \cdot K_{BS}}{\omega_1}$ . Although the scope of the present invention is not limited in this respect, the selection of  $K_{BS}$  and an intermediate transformation ratio may not result in the negative capacitor  $C_A$  value in Equation (4).

[0024] Reference is now made to FIG. 3, which schematically illustrates graphs 310, 320 helpful in demonstrating the efficiency of an outphasing transmitter according to an exemplary embodiment of the present invention. Graph 310 and 320 depict the efficiency of transmitter 200 as a function of variations in the output power. Both graphs indicate an increase in efficiency when the output power is increased. The first graph 310 represents exemplary simulation results while the second graph represents results of actual measurements performed on a transmitter according to embodiments of the invention. It should be noted that graphs 310, 320 represent merely examples of efficiency curves and that actual efficiency curves of embodiments of the present invention may vary according to specific designs and implementations. It should be understood that the scope of the present invention is in no way limited to those examples.

[0025] While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes, and equivalents will now occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications, substitutions, changes and equivalents as may fall within the true spirit of the invention.